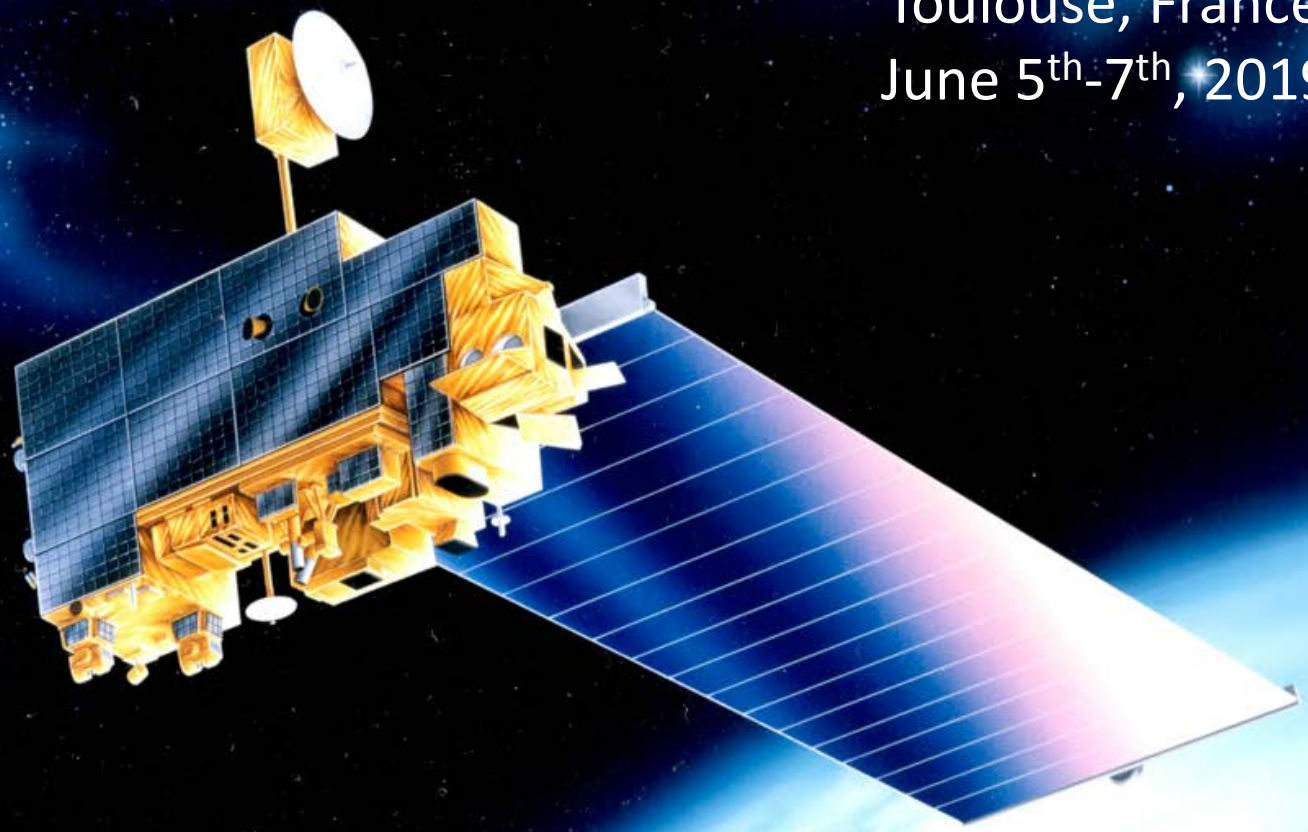
EOS Terra

Mission Status
Constellation MOWG

Toulouse, France

June 5th-7th, 2019



Dimitrios Mantziaras

Terra Mission Director - Code 428

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Dimitrios.C.Mantziaras@nasa.gov

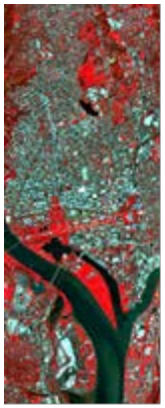
Topics

- Mission Summary
- Spacecraft Subsystems Summary
- Recent Activities
- Inclination Adjust Maneuvers
- Conjunction History
- End-Of-Mission Plan
- Upcoming Activities
- Summary
- Backup Slides

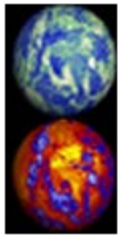
Terra Mission Overview

Terra Features

- **Launch Date:** *December 18,1999 (Atlas IIAS, VAFB)*
- **Orbit:** *705 km, Sun-synchronous polar, 98.2º Inclination, 10:30 AM MLT descending node*
- **Instrument Payload:**
  - **ASTER (*SWIR*, TIR & VNIR) -** *Advanced Spaceborne Thermal Emission and Reflection Radiometer* (Japan)
  - **CERES (Fore & Aft) -** *Clouds and the Earth's Radiant Energy System* (USA – Langley)
  - **MISR -** *Multi-angle Imaging Spectro-Radiometer* (USA – JPL)
  - **MODIS -** *Moderate Resolution Imaging Spectro-radiometer* (USA – GSFC)
  - **MOPITT -** *Measurement of Pollution in the Troposphere* (Canada)
- **Project Management:** *Earth Science Mission Operations (ESMO)*
- **Spacecraft Flight Operations:** *Contracted by GSFC to KBR team and supported by NASA NENs and TDRSS*
- **Instrument Operations and Science Data processing:** *Performed at respective Instrument Locations where developed*
- **Mission Duration:** *Successfully completed Prime mission of 5 years. Currently in Extended Operations.*
- **Distributed Active Archive Centers:** *LP DAAC – MODIS, ASTER; Langley DAAC – CERES, MISR, MOPITT*



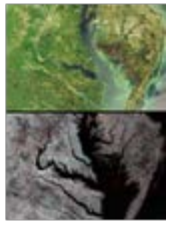
ASTER



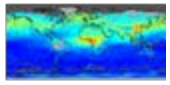
CERES

Terra (EOS AM-1)

MODIS



MISR



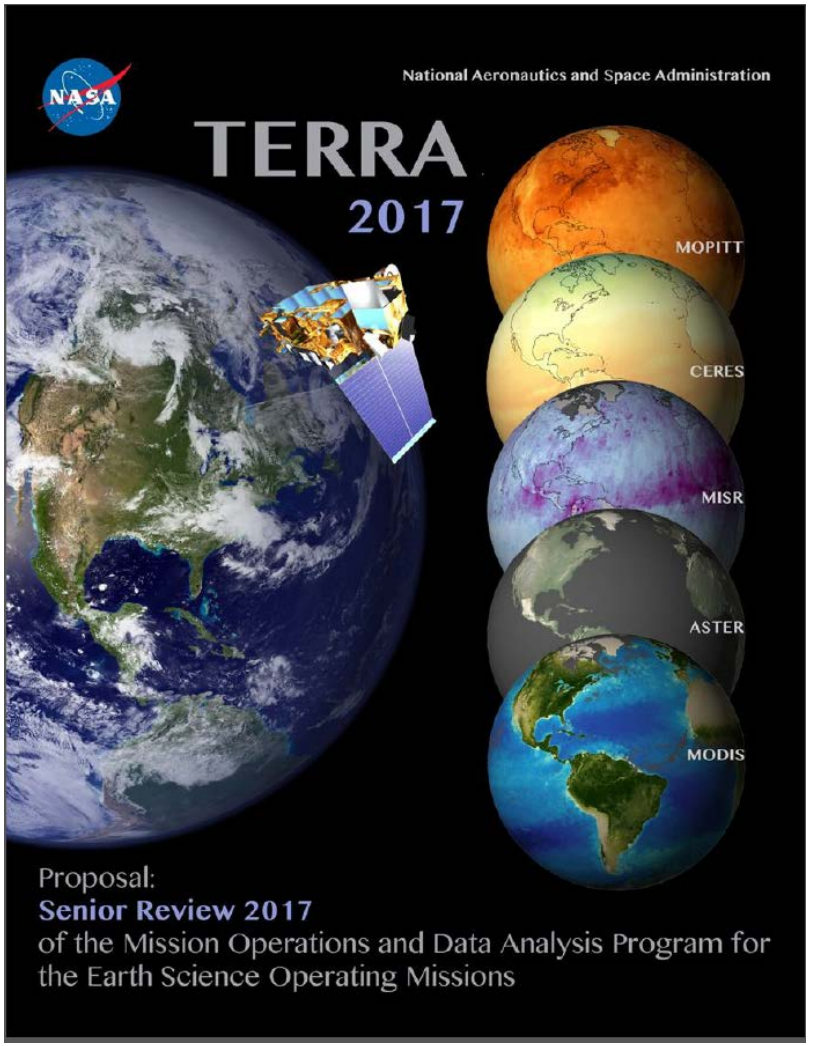
MOPITT

Science

- *The primary objective of the Terra Mission is to simultaneously study clouds, water vapor, aerosol, trace gases, land surface and oceanic properties, as well as the interaction between them and their effect on the Earth's energy budget and climate.*

EOS Terra Mission Summary

- **May 2017: Mission Extension Senior Review Proposal Panel Report**
  - Mission extension through FY23
  - Senior Review submission delivered in Mar 2017
  - Next submission ~March 2020
- **2019 Inclination Adjust Maneuvers**
  - Spring 2019 Inclination Maneuvers
    - IAM #54 – March 6th
  - Fall 2019 Inclination Maneuvers
    - IAM #55 – TBD
    - IAM #56 – TBD
- **10/06/18: Terra 100,000 Orbits**
- **12/18/18: Terra 19-Year Anniversary**
  - 5-Year Design Life, 6 year goal
  - Reliability Estimates thru 2025+
  - Consumables through 2020+
- **April 2019: EOS Flight Operations Annual Review #13 - Complete**



Terra Spacecraft Status

All subsystems on Primary Hardware except as noted

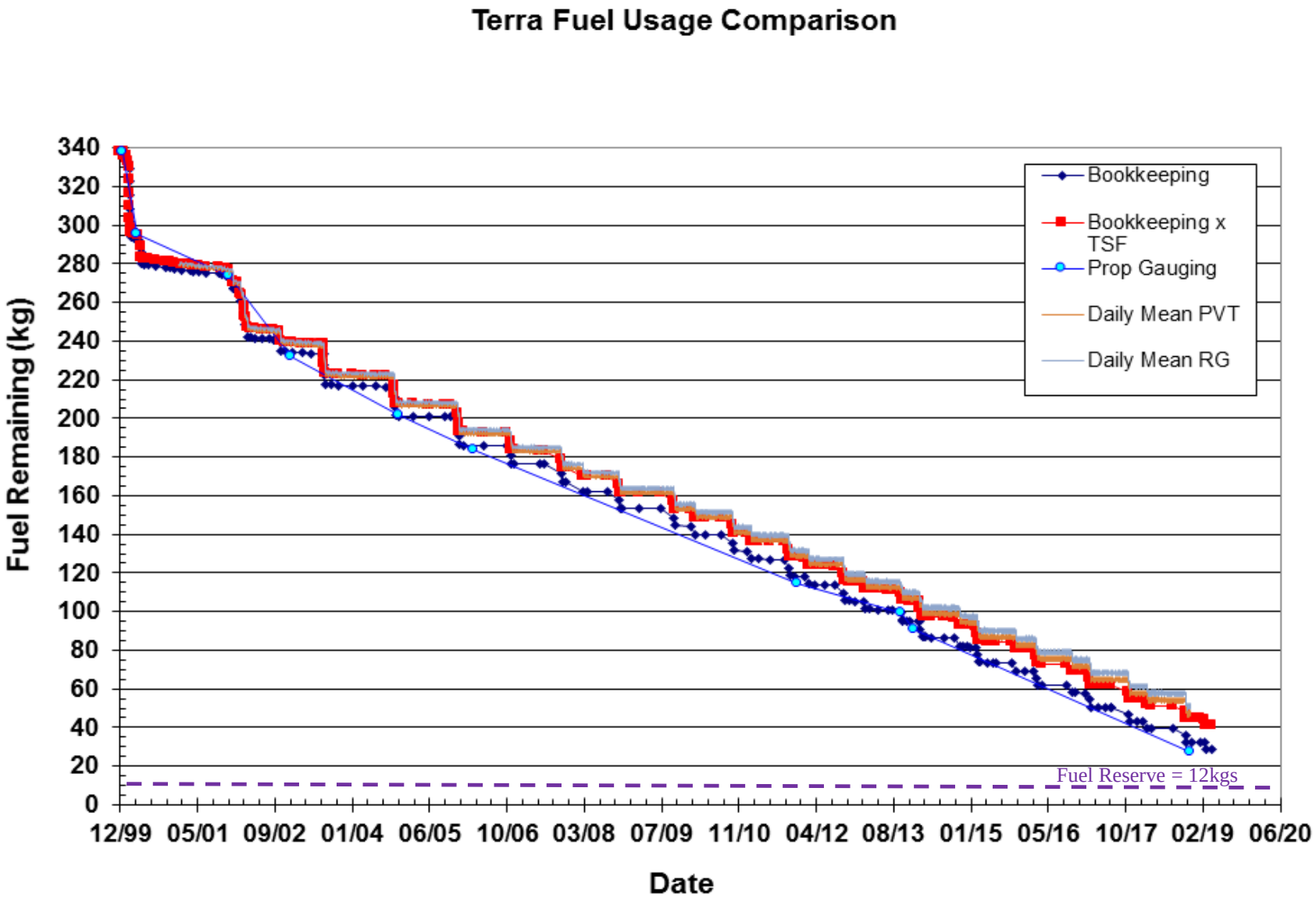
- **Command & Data Handling** (CDH) – **Nominal**
  - Solid State Recorder (SSR) – holds ~1 orbit of data
  - **11** of 58 SSR Printed Wire Assembly tripped off resulting in reduced recording capacity
- **Communications** (COMM) – **Nominal**
  - DAS Modulator Failure on 05/29/2008 (Operating on Redundant)
  - Use K-Band primarily, X-Band as needed for Science Playback
- **Electrical Power System** (EPS) – **Good**
  - Battery Cell and Heater Controller Anomaly (10/13/2009)
  - 1 of 24 Solar Panel Failed (9/24/2000)
- **Flight Software** (FSW) – **Nominal**
- **Guidance, Navigation & Control** (GN&C) – **Nominal**
  - Minor loss of sensitivity in SSSTs – updated tracker biases to compensate
- **Propulsion** (PROP) – **Nominal**
- **Thermal Control System** (TCS) – **Nominal**
- **Instruments** (INST) – **Nominal**
  - Only ASTER SWIR failed, all other instruments are taking science

Spacecraft Component Status

Subsystem	Component	Design	Current	Capability	Comments
EPS	Solar Array	24 Shunts	23 Shunts	96%	Degradation is minimal. Fully capable of supporting mission thru 2020 unless future failures occur
	Batteries	108 Cells	107 Cells	99%	BBAT cell #50 failed on 10/15/09.
	Batteries	36 Heater Controls	28 Heater Controls	77%	BBAT heater control failed on 4 of 9 heater groups on primary, redundant, and survival. Battery cell charging/discharging and the remaining heater groups are preventing cells from freezing. PBAT heater control performance is nominal.
TCS	MOPITTCPHTS	2	2	Full	Performance is nominal
	SWIR CPHTS	2	2	Full	Performance is nominal
	TIR CPHTS	2	2	Full	Random temperature fluctuations. Performance within requirements.
SCC	SCC	2	2	Full	Performance is nominal
COMM	HGA	2	2	Full	MDA BITE failures occur 2-3/week due to SEU. Recoverable
	X-Band	2	1	75%	DAS Modulator 1 failed (50%). Solid State Power Amplifier redundancy still available (100%).
	CTIU	2	2	Full	Performance is nominal
	OMNI	2	2	Full	Performance is nominal
CDH	MO	2	2	Full	Drift rate changes have occurred since 10/3/10. Performance is within requirements.
	SFE	2	2	Full	SFE SEU occur 1-2/year. Recoverable
	SSR	59 PWA	**48** PWA	81.4%	Recycle of Data Memory Unit likely to recover all Printed Wire Assemblies
GNC	IRU	3	3	Full	Performance is nominal. 2 for 3 redundancy
	TAM	2	2	Full	Performance is nominal
	SSST	2	2	Full	Minor loss of sensitivity in SSSTs – tracker biases updated
	CSS	2	2	Full	Performance is nominal
	ESA	2	2	Full	Performance is nominal
	FSS	1	1	Full	Performance is nominal. Not currently used
	RWA	4	4	Full	Performance is nominal. 3 for 4 redundancy
	MTR	3	3	Full	Performance is nominal
Prop	REAs	16	16	Full	Performance is nominal
Instruments	ASTER - SWIR	2	2	0%	Cooler is unable to maintain detector temperature. Science Data is unusable (Fully Saturated) and is no longer being recorded. Still collecting and monitoring Engineering data.
	ASTER - TIR	2	2	Full	Performance is nominal
	ASTER - VNIR	2	2	Full	Performance is nominal
	CERES - Aft	1	1	Full	Performance is nominal
	CERES - Fore	1	1	Full	Performance is nominal
	MISR	2	2	Full	Performance is nominal
	MODIS	2	1	50%	Power Supply #2 failed, Formatter A degraded, cross-strapped. **All Science is nominal.**
	MOPITT	2	1	50%	Displacer B and Chopper Motor failed. **Loss of redundancy only. All Science is nominal.**

Lifetime Estimates

Fuel Remaining



Recent Activities

- **Propulsive Maneuvers**
  - Drag Make Up Maneuver (DMU) #105 executed on 01/26/18
  - Inclination Adjust Maneuver (IAM) #51 on 02/22/18
  - Risk Mitigation Maneuver (RMM) #12 (DMU #106) executed on 03/16/18
  - Risk Mitigation Maneuver (RMM) #13 (DMU #107) executed on 08/10/18
  - Inclination Adjust Maneuver (IAM) #52 executed on 10/25/18
  - Inclination Adjust Maneuver (IAM) #53 executed on 11/01/18
  - Drag Make Up Maneuver (DMU) #108 executed on 12/04/18
  - Drag Make Up Maneuver (DMU) #109 executed on 01/30/19
  - Risk Mitigation Maneuver (RMM) #14 (DMU #110) executed on 02/26/19
  - Inclination Adjust Maneuver (IAM) #54 executed on 03/06/19
  - Risk Mitigation Maneuver (RMM) #15 (DMU #111) executed on 04/12/19
  - Inclination Adjust Maneuvers (IAM) #55 and #56 planned for October 2019
  - Inclination Adjust Maneuver (IAM) #57 planned for February 2020
  - Inclination Adjust Maneuver (IAM) #58 planned for October 2020
    - Planned to be final IAM
    - After IAM #58 Mean Local Time (MLT) will be allowed to drift

- **Calibration Maneuvers**
  - MODIS Roll #182 executed on 01/06/18
  - MODIS Roll #183 executed on 02/04/18
  - MODIS Roll #184 executed on 03/06/18
  - MODIS Roll #185 waived-off on 04/04/18 due to scheduling error
  - MODIS Roll #186 executed on 06/03/18
  - MODIS Roll #187 executed on 07/03/18
  - MODIS Roll #188 executed on 08/01/18
  - MODIS Roll #189 executed on 08/30/18
  - MODIS Roll #190 executed on 09/29/18
  - MODIS Roll #191 executed on 10/29/18
  - MODIS Roll #192 executed on 11/27/18
  - MODIS Roll #193 executed on 12/26/18
  - MODIS Roll #194 executed on 01/25/19
  - MODIS Roll #195 executed on 02/23/19
  - MODIS Roll #196 executed on 03/25/19
  - MODIS Roll #197 planned for June 2019

- **01/09/18: ERPS Induced Clock Coor. Errors**
- **02/15/18: Terra Lunar Induced Solar Eclipse #41**
- **03/12/18 – 03/23/18 : MOPITT Decontamination and Hot Cal.**
- **04/19/18: CERES Safe Sequence and Calibration Load Uplink**
- **05/31/18: Auto-LUR update patch uplinked**
- **06/06/18 - 06/07/18: ASTER Science Team and Interface Meeting**
- **06/29/18: BPC Channel-A Enable TMON**
- **07/13/18: Terra Lunar Induced Solar Eclipse #42**
- **07/19/18: BBAT TMON Response Update Uplink**
- **07/26/18: CERES PROM_DUMP2 Uplink**
- **08/11/19: Terra Lunar Induced Solar Eclipse #43**
- **08/16/18: Safe Hold Sequence TONS update uplink**
- **09/27/18: Terra ATC Expired**
- **09/27/18 – 10/05/18: ATC Expire Instrument Recovery**
- **10/06/18: Terra Orbit #100,000**
- **10/08/18: MOPITT Decontamination Hot Cal.**
- **10/08/18: Terra HGA Power Off Anomaly**
- **10/11/18: ACE-B Rate Sensor Select Anomaly**
- **01/06/19: Terra Lunar Induced Solar Eclipse #44**
- **01/21/19: ASTER Skipped EDU**
- **02/14/19: Terra TMON 7 (ACE-B Sensor Select) Update Uplink**
- **03/11/19 – 03/22/19: MOPITT Decontamination and Hot Cal.**

Inclination Adjust Maneuvers

- **Inclination Adjust Maneuvers used to maintain nominal spacecraft mean local time (descending node) of 10:30 AM**
  - **10/25/2018 IAM #52 (320 sec burn) executed successfully**
  - **11/01/2018 IAM #53 (320 sec burn) executed successfully**
  - **03/06/2019 IAM #54 (320 sec burn) executed successfully**

- **Predictions indicate need to perform 3-4 maneuvers per year**
  - **2017: (2 in Spring, 2 in Fall) -- COMPLETE**
  - **2018: (1 in Spring, 2 in Fall) – COMPLETE**
  - **2019: (1 in Spring, 2 in Fall) – Spring Maneuver complete, Fall Maneuvers upcoming**
  - **2020: (2 in Spring, 0 in Fall) -- last inclinations for Terra mission**

Terra High Interest Events

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2018 (T1-T4)	0	1	2	0	0	1	0	1	1	0	0	0	6
Tier 3	0	1	1	0	0	1	0	0	1	0	0	0	4
Tier 4	0	0	1	0	0	0	0	1	0	0	0	0	2
2019 (T1-T4)	0	2	0	2									4
Tier 3	0	1	0	0									1
Tier 4	0	1	0	1									2

CARA Defines the 4 Tiers as: T1 – Notify (email/phone), T2 – Conduct Briefing, T3 – Plan Maneuver, T4 – Execute Maneuver

- **2010**: 5 HIEs – 1 DAM performed on 01/22/2010: Terra vs. 34700 CA on 1/23 @ 20:46z
- **2011**: 20 HIEs – 2 DAM planned and waived off
- **2012**: 19 HIEs – 1 maneuver waived off due to CA
- **2013**: 17 HIEs – 7 that required significant action
- **2014:** 24 HIEs – 6 that required DAM execution or nominal maneuver waive-off and replanning
- **2015:** 33 HIEs – 8 that required DAM execution or nominal maneuver waive-off and replanning
- **2016:** 11 HIEs – 0 that required DAM execution or nominal maneuver waive-off and replanning
- **2017:** 8 HIEs – 1 that required DAM execution or nominal maneuver waive-off and replanning
- **2018**: **6 HIEs – 2** that required DAM execution or nominal maneuver waive-off and replanning
- **2019 to present:** **3 HIEs** that required DAM execution or maneuver waive-off and replanning
  - DAM #14 performed on 2/25; Terra vs. 28598 with TCA = 2/26 @ 07:16z
  - DAM #15 performed on 4/12; Terra vs. 37518 with TCA = 4/13 @ 02:49z

ESMO RMM Planning Automation

- **ESMO has updated its Close Approach (CA) Process Flow to move towards a more Automated approach**
  - Prepares for future increased object catalog w/ Space Fence
  - Reduces workload for each event
  - Keeps solution “at the ready” for short notice events
- **ESMO Flight Dynamics team has developed an autonomous ephem generation tool**
- **Ephems built off optimal and constrained cases solved for by the Collision Risk Management System (CRMS)**
- **CARA accepts delivery of these ephems and ships them to JSpOC for screening**
  - Delivery to CARA is now automatic based on logic built into the FDS ephem tool to whittle ephems down from maximum of eight generated to a maximum of five delivered
  - Any other options needed can be sent manually
- **Screening results automatically compiled and outputted via an email report from CRMS**
- **Auto Ephem Generation implemented in February 2017**
- **Auto Ephem Delivery implemented in February 2018**
- **ESMO now exercising the CARA Devolution Pilot Program (other presentation)**

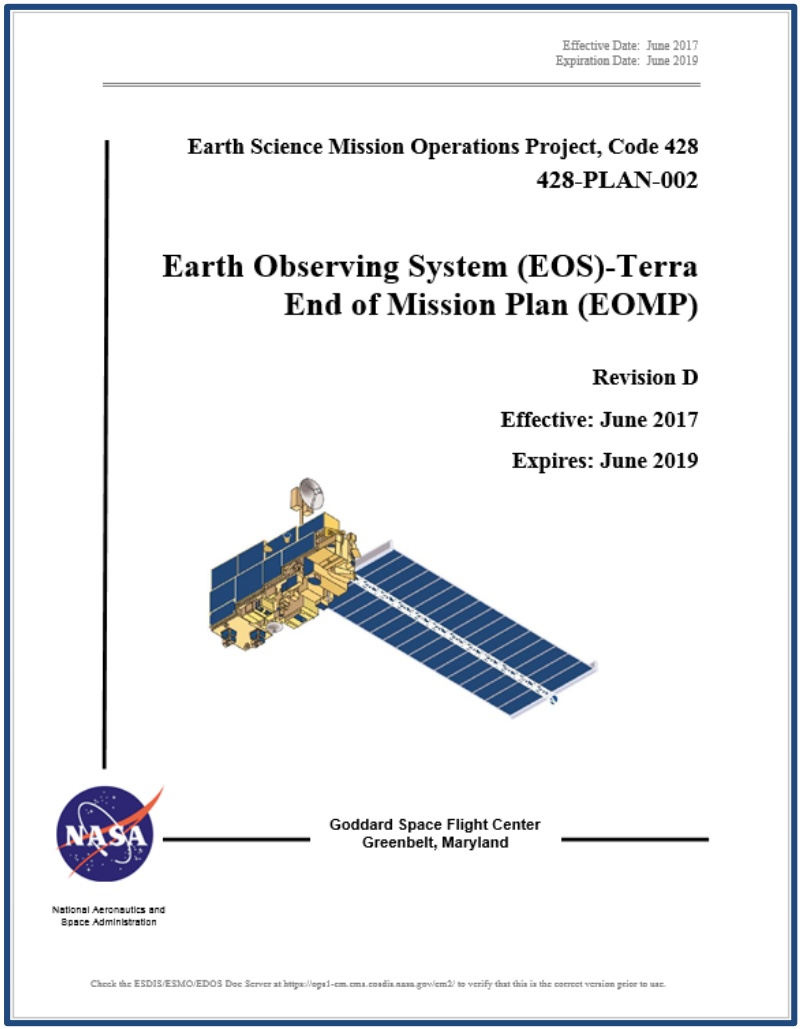
Terra End-of-Mission Plan

Document Status

- Rev D - End-of-Mission Plan Document has been revised and under review cycle
- APPROVED - NASA HQ Signed in October 2018

Content

- Terra will continue normal operations through October 2020
- Once all non-reserved fuel has been used, MLT will be drifted to 10:15 AM
- August 2022, Terra exits constellation
- Remaining fuel used to lower perigee prior to spacecraft passivation
- Exit plan is consistent with the current Constellation Operations Coordination Plan



Effective Date: June 2017
Expiration Date: June 2019

Earth Science Mission Operations Project, Code 428
428-PLAN-002

Earth Observing System (EOS)-Terra
End of Mission Plan (EOMP)

Revision D

Effective: June 2017

Expires: June 2019

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

Check the ESDIS/ESMO/EDOS Doc Server at https://ops1-cm.cms.esdis.nasa.gov/cm2/ to verify that this is the correct version prior to use.

Upcoming Activities

Upcoming Activities	
Terra FSSE CCB	**05/08/19 @ 10 AM**
Terra Full Team Retrograde Simulation	**05/15/19**
Terra Instrument Telecon	**05/20/19**
MISR Bi-Monthly Calibration	**06/04/19**
ASTER Science Team Meeting and Interface Meeting	**06/10/19 – 06/13/19**
Retrograde/Decommission Preparation	**Ongoing**

FUTURE PLAN

Terra Lifetime Maneuvers

- **Remaining Orbit Maintenance Maneuvers**

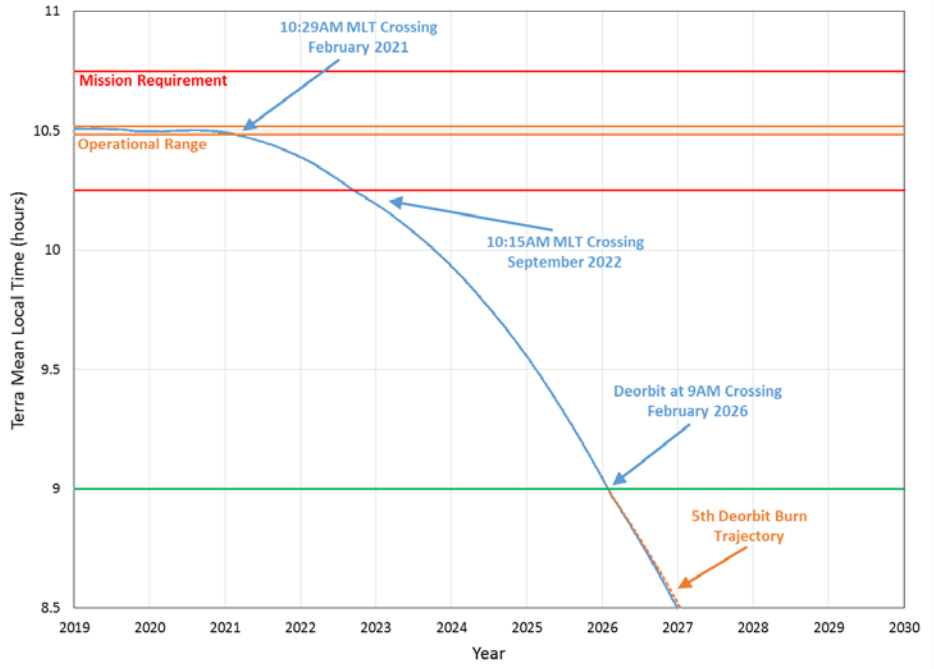
Mission Year	Inclination Maneuvers	DMU Maneuvers	Fuel Used (kg)	Fuel Remaining (kg)
2018	1 Spring, 2 Fall	4	10.783	45.616
2019	1 Spring, 2 Fall	3	10.648	34.967
2020	2 Spring, 0 Fall	4	7.221	27.746
2021	0 Spring, 0 Fall	6	0.828	26.918
2022	0 Spring, 0 Fall	5	0.824	26.094

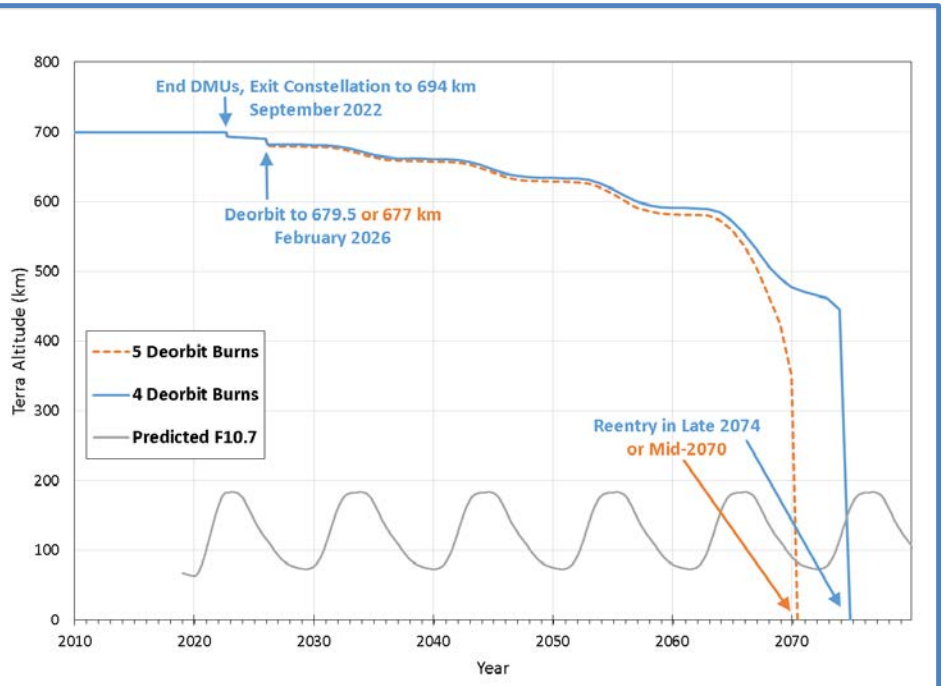
- **Constellation Exit and Deorbit Maneuvers**

Mission Date	Maneuver Type	Fuel Used (kg)	Fuel Remaining (kg)
09/22/2022	Envelope Exit #1	3.429	22.666
09/22/2022	Envelope Exit #2	3.409	19.256
2/12/2026	Deorbit #1	3.372	15.884
2/17/2026	Deorbit #2	3.354	12.531
2/19/2026	Deorbit #3	3.336	9.195
2/24/2026	Deorbit #4	3.318	5.877
2/26/2026	Deorbit #5 (95% Duration)	3.125	2.752

Terra Lifetime Maneuvers

MLT and Altitude Predictions

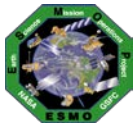




Decommissioning Plan	Exit Year	Deorbit Year	De-orbit Burns (#)	Apogee at Depletion (km)	Perigee at Depletion (km)	End of Mission (EOM)	EOM to Reentry (years)	Reentry Date
Baseline (4 x 320-sec burns)	2022	2026	4	692.8	672.9	2026	48	2074
Baseline plus 5th 304-sec deorbit burn	2022	2026	5	692.1	667.9	2026	44	2070

Summary

- **Terra remains very healthy 19+ years into the mission**
  - Electrical Power Subsystem performance has been stabilized following 2009 anomaly
  - Fuel Remaining to continue operations to 2020 and beyond
- **Data Capture percentages continue at ~100%**
- **Collision Avoidance events continue to be part of routine ops**
  - Low atmospheric drag is providing additional challenges
- **End of Mission Plan (Rev D) officially approved/signed**
  - Goddard signed/approved version made it to NASA HQ on 05/11/18
  - **All signatures received in October 2018**
- **Plan is for Terra to Exit Constellation in August 2022 and end mission in early 2026**



Questions

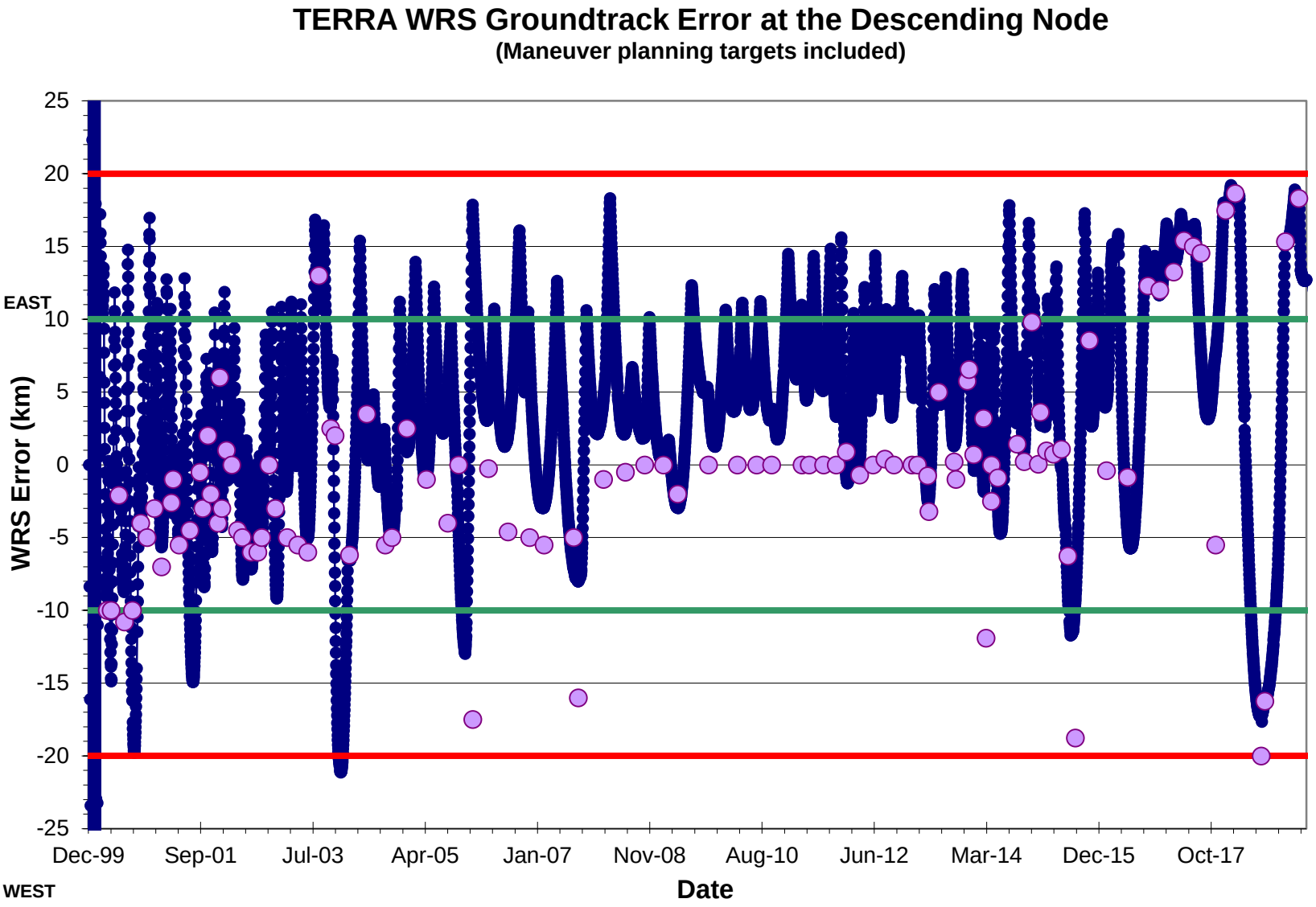
Additional Slides

- Orbit / Inclination / MLT Maintenance
- WRS Ground Track Error
- EPS Performance
- Drag Model Info
- OSMA Waiver Email
- NASA HQ Email

Orbit/Inclination/MLT Maintenance

- **Requirement**: Mean Local Time (MLT) maintained between 10:15 and 10:45 measured at the Descending Node.
- **Goal**: Maintain Terra mean local time of the descending node (MLTDN) below 10:31.
- **Constraint**: OCO-2 has requested Terra maintain a MLT less than 10:31 for the duration of its lifetime to maintain a safe separation at the poles.
- **Requirement**: Maintain WRS-2 ground track error, 0 +/-20 km.
- **Requirement**: Maintain Frozen orbit with Argument of Perigee at 90 degrees +/-20 and Eccentricity of 0.0012 +/- 0.0004.
- **Constraint**: Maximum burn duration limited to 320 seconds by spacecraft manufacturer. Complete yaw slews and inclination maneuvers during spacecraft orbital night. Maneuver close to spring and fall equinox to maximize efficiency.

WRS Ground Track Error (GTE)



EPS Subsystem Performance

- **Bus Load:** Nominal
  - Average bus load: 2306.74 Watts
  - Average housekeeping current: 11.903 A
  - Total instrument current: 7.121 A
- **Battery Performance**: **Nominal with exception of anomalous BBAT condition**
  - BBAT cell # 50 failed following IAM #24 on October 13 (DOY 286) 2009
    - BBAT Voltage Temperature curve changed to better reflect a failed cell
  - BBAT heater control electronics (HCE) anomaly occurred following IAM #24 on October 13 (DOY 286) 2009
    - Performed soft reset, power cycle, switching to redundant side and re-enabling one of the nonfunctioning heater groups to recover HCE functionality without success
    - At least 4 of 9 BBAT heater groups are no longer being controlled
    - Heater control setpoints changed for controllable heater groups to reduce the thermal gradient
  - PBAT Charge/Discharge Ratio was reduced from 105% to 104% on April 25, 2013 in an effort to extend PBAT life
  - PBAT BPC Channel A Disabled January 14, 2014; increases BBAT cold temperatures due to increased discharge
  - PBAT Charge/Discharge Ratio was reduced from 104% to 103% on August 20, 2015 in an effort to extend PBAT life
    - A number of PBAT cells (18, 26, 38) appear to be decreasing in pressure [could be long-term effect of C/D Ratio change in 2015]
      - Pressure analysis by EPS/TCS Engineer and battery experts concluded that batteries were in good health
- **Battery Temperatures**: **Nominal with exception of anomalous BBAT data**
  - PBAT and half of BBAT Battery temperatures are regulated by flight software to ≈ -1°C to -5°C
  - Almost half of BBAT cell temperatures are below normal (but stable) in the -5°C to -13°C range
- **Battery Voltages** (BBAT)
  - Minimum battery voltages at 66.114 Volts
- **Solar Array**
  - Last offset adjustment performed on January 7, 2019
  - Average drift rate for the month, 0.062 deg/day
  - Present offset drift rate is decreasing
- **BBAT Cell with Lowest Temperature** (excluding Cell #50)
  - Cell # 21 : --10.69°C
  - Thermal Gradient(avg): 7.21°C

OSMA Official Direction

From: Aleman, Suzanne M. (HQ-GD000)
Sent: Wednesday, November 02, 2016 11:37 AM
To: Yuhas, Cheryl L. (HQ-DK000) <cheryl.l.yuhas@nasa.gov>
Cc: Liou, Jer-chyi (JSC-XI411) <jer-chyi.liou-1@nasa.gov>; Hull, Scott M. (GSFC-5920) <scott.m.hull@nasa.gov>
Subject: FW: Terra need for Orbital Debris waivers

Hi Cheryl,

I received you voice mail regarding the question on whether a waiver is needed for the 25 year rule for TERRA.

I consulted with J. C Liou on this question we have concluded that a waiver is not needed. Please see the e-mails below.

Please let me know if you have any questions.

Best regards,

Sue Aleman
NASA HQ OSMA
MMOD Program Executive

NASA HQ Official Direction

From: Webb, Charles E. (HQ-DK000)
Sent: Friday, February 02, 2018 3:45 PM
To: Mantziaras, Dimitrios C. (GSFC-4280) <dimitrios.c.mantziaras@nasa.gov>
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Subject: Re: Terra Future Maneuver Plans Slides

Dimitrios,

Sandra Cauffman has given HQ/ESD concurrence on the IAM plans for Terra through 2020. You're all set for the February maneuvers and beyond.

Have a good weekend,

Charles